

Segment Lining in small diameters:
machine solutions and case studies.

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Small Diameter Segment Lining.
Application fields in Utility Tunnelling.

Diameter range: ID 2400 – ID 4000

- ▶ Sewage & Deep Sewer Tunnels
- ▶ Water Tunnels
- ▶ Casing Tunnels
 - ▶ for cables
 - ▶ for pipelines

Advantages of Segment Lining:

- ▶ Long drives possible ($\geq 10,000\text{m}$)
- ▶ Tight curve radius possible ($\geq 80\text{m}$)
- ▶ Minimization of risks

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Small Diameter Segment Lining.
DIN EN 16191:2014 ‘Safety requirements for tunnelling machinery’.

ID in mm	≤ 2000	2000 – 3500	3500 – 6000	$\geq 6000\text{mm}$
Access height x width	① 0.7 x 0.45m	1.0 x 0.45m	1.4 x 0.45m	1.9 x 0.45m
Exception for obstacles on less than 4m length		0.7 x 0.45m	1.0 x 0.45m	
Min. access cross section	② 0.5m ²	0.6m ²	0.8m ²	1.2m ²
Min. walking width, with railing	③ 0.3m clear	0.3m clear	0.3m clear	0.3m clear

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Small Diameter Segment Lining.
DIN EN 16191:2014 ‘Safety requirements for tunnelling machinery’.

► Further measures required:

- ▶ Explosion-proof monitoring system of oxygen supply and toxic gases
- ▶ **Explosion-proof machine design** obligatory, if gases cannot be excluded
- ▶ Fire detection system with alarm
- ▶ Fire extinguishing unit, fix where possible
- ▶ Higher **noise protection** standards
- ▶ Independent **emergency lighting**

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Small Diameter Segment Lining.
Key factors for machine design.

Ventilation:
▪ Ø 500 – 1000mm
▪ Circular / elliptical

Access area required for safety standards

Width of train (EPB) OR Tunnel pump size (AVN)

Width of train:
• Size of locomotive
• Length of segments

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Small Diameter Segment Lining.
Machine concepts and logistics.

Example ID 2500
Loco: 800mm | Segment: 800mm | Vent. Ø 500mm

Example ID 3000
Loco: 1000mm | Segment: 1200mm | Vent. Ø 700mm

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Small Diameter Segment Lining.
Impact of ventilation diameter on drive length.

Internal Diameter	Air Duct Diameter	Possible Drive Length
2.500 mm	500 mm	2.000 m
2.500 mm	700 mm	4.000 m
3.000 mm	700 mm	5.500 m
3.000 mm	1.000 mm	8.000 m
3.500 mm	1.200 mm	10.000 m

Attention:

- These figures are only rough guidelines, depending on individual project and design parameters
- Based on 0.3 m/s air flow in the tunnel, max. pressure in air duct 6.000 Pa
- no booster fans in tunnel!

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Small Diameter Segment Lining.
Machine concepts and logistics.

General conditions:

- Trend: projects require longer tunnels
- Geology can change drastically along the tunnel
- Herrenknecht Combined Shields (HCS) help overcome these constraints

Key points for logistics and machine design:

- Segment Length: min. 800 mm
- Width of tunnel train: min. 800 mm
- Ventilation: min. Ø 500m

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Small Diameter Segment Lining.
Machine concepts | AVN Slurry Machine.

- Allrounder** in complex geologies
 - Suitable for high water pressures
- Tunnel pump stations needed**
 - Number of tunnel pumps increases with longer drives
- Reduced logistics** in tunnel and shaft
 - slurry lines, segments, grout,
 - no muck skips in tunnel

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Small Diameter Segment Lining.
Machine concepts | EPB Shields.

- Economical** in suitable geologies
- For longer tunnels: **California crossings**
- Ground water** handling capability
- Active face pressure support**
- Muck skip or tunnel belt conveyor (ID>3200mm) for spoil transport

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Small Diameter Segment Lining.
Machine concepts | HCS Herrenknecht Combined Shields.

- TBM** - in rock
- Slurry** - in permeable soil with high water pressure (e.g. fault zones)
- EPB** - in rock
- EPB (open mode) in fractured rock with low water pressure
- EPB (closed mode) in soft, cohesive soils
- AVN (crusher and slurry circuit) in permeable soil with presence of huge amount of water and high pressure

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EPB 3000 with Slurry Box for Abu Dhabi.
Used for long distance Pipe Jacking.

- M-1720M, EPB 3000 with Slurry Box, extended for ID 3100, OD 3745
- In operation for STEP Project, Abu Dhabi
- 4.5km of tunnel installed
- Max. drive length: 1,600m
- Geology: sand, sandstone, clay, gravel, rock

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EPB 3000 with Slurryfier Box for Abu Dhabi.
Used for long distance Pipe Jacking.

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Push module.
To change from Pipe Jacking to Segment Lining.

- ▶ Reference Project: Colector Interceptor General del Río Nalon", Oviedo, Spain
- ▶ Sewage tunnel | Pipe Jacking ID 2000
- ▶ Pipe Jacking stuck due to change in geology to rock conditions
- ▶ Tunnel length: 1,200 m | 700 m with Segment Lining
- ▶ Segment ID 2,000 | OD 2,270 mm | Width 750 mm | Thickness 135 mm

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Small Diameter Segment Lining.
EPB used in tight curve projects.

- ▶ M-687 EPB3600, Bangkok, Thailand, $r = 80m$
- ▶ M-1586 EPB3500, Guangzhou, China, $r = 120m$
- ▶ M-1834/M-1835 EPB2800, Makkah, Saudi Arabia, $r = 80m$
- ▶ M-1856/M-1857, EPB2600, Emscher, Germany, $r = 200m$

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Small Diameter Segment Lining.
EPB used in tight curve projects.

- ▶ 2 x EPB 2800 AH, OD3510, Segment Lining
- ▶ Location: Makkah, Saudi Arabia
- ▶ Project: Makkah Haram Sewer Line
- ▶ Tunnel Length (3 drives): 4,479m, $r = 80m$
- ▶ Geology: rock, weathered rock, soft soil

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Small Diameter Segment Lining.
EPB used in tight curve projects.

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Small Diameter Segment Lining.
EPB used in tight curve projects.

- ▶ 2 x EPB 2600 , OD3225, Segment Lining
- ▶ Location: Bottrop, Germany
- ▶ Project: Emscher (ongoing)
- ▶ Tunnel: Length = $2 \times 9,800m$, $r = 200m$
- ▶ Geology: Emscher marl

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Small Diameter Segment Lining.
EPB used in tight curve projects.



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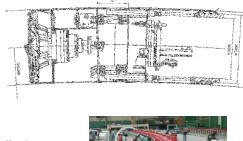
Small Diameter Segment Lining.
EPB used in tight curve projects.



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Small Diameter Segment Lining.
EPB used in tight curve projects. Technical measures.

- ▶ Airlock integrated in steelwork of Shield
 - ▶ compressed air interventions possible for future projects
 - ▶ upgrade for installations and air regulation unit can be carried out at a later date.
- ▶ Articulation joint
 - ▶ Min. curve radius 100m (80m correction radius)
- ▶ Belt conveyor angle adjustable for curve drive
- ▶ Use of shorter tunnel rails or pre-bent rails in 100m curve
- ▶ Backup trailer concept with dedicated rails to counter roll of gantries




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Small Diameter Segment Lining.
Long drives.

- ▶ M-1494M, EPB 3000 AH, OD3670mm
- ▶ Contractor: Construtora Odebrecht S.A.
- ▶ Sewer Project: Saneamiento de la bahía y de la ciudad de Panamá
- ▶ Tunnel length: 8,018m in one drive!
- ▶ Geology: 77% conglomerate volcanic rock, 10% basalt, 13% sandstone siltstone, groundwater to 2 bar
- ▶ Best monthly performance: 718m




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Segment concepts.
Requirements on Water and Wastewater Structures.

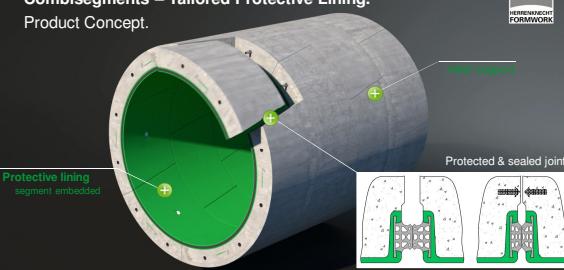
- ▶ Rising environmental awareness (exfiltration and infiltration)
- ▶ Increasing durability demands ⇒ concrete protection
- ▶ Hydraulically optimized flow conditions ⇒ surface smoothness
- ▶ Accelerated tunnel construction and cost-efficient Corrosion Protection Lining (CPL)
- ▶ CPL successfully applied in demanding projects, e.g.
STEP-Abu Dhabi (16.2 km, ID 4m), DTSS P1-Singapore (12 km, ID 3-6m)



Exposure of reinforcement
Deposits and stalactites

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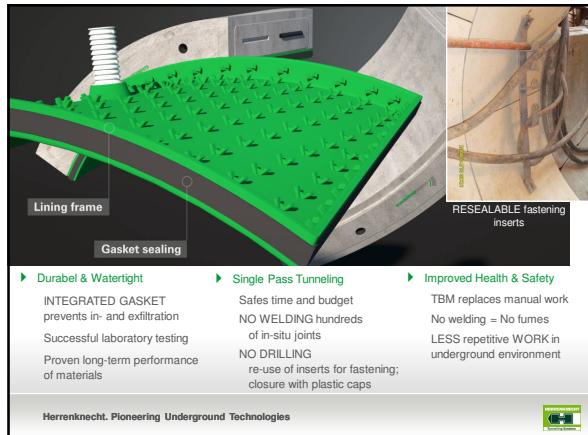
Combisegments – Tailored Protective Lining.
Product Concept.



Initial support
Protective lining segment embedded
Protected & sealed joints

- ▶ Protective lining with integrated gasket
- ▶ Embedded inserts for handling and fastening
- ▶ Fast and simple segment manufacturing
- ▶ Single-pass tunneling

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Combisegments – Tailored Protective Lining.

References.

- ▶ **West Trunk Sewer Phase 2, Canada, 2017**
ID 3000, OD 3400, ring width 1200, ring config. 4+2
L ~ 252m of 2.1 km tunnel will be constructed using Combisegments Panel Type II HDPE
- ▶ **Moscow Sewage System, Russia, 2010**
ID 2750, OD 3150, ring config. 5+1
L ~ 500 m using previous variant of Combisegments with GRP Inliner

Moscow, Russia, 2010

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